Coupling Simulated Ocean Reflectance to the Atmospheric Correction of Hyperpsectral Images

W. Paul Bissett
Florida Environmental Research Institute
4807 Bayshore Blvd.
Suite 101
Tampa, FL 33611
phone: (813) 837-3374 x102 fax: (813) 902-9758 email: pbissett@flenvironmental.org

Award Number: N00014-00-1-0514
http://www.flenvironmental.org

LONG-TERM GOALS

Aircraft and satellite Remote Sensing [RS] platforms provide spatial and temporal coverage of oceanic water conditions that are unobtainable by any other cost effective means. The hope of Hyperspectral RS [HRS] data is that it will provide the necessary data stream to simultaneously describe the atmospheric and water column optical properties. The goal of these hyperspectral programs is to develop the instruments, platforms, and data analysis techniques to achieve the depth-dependent description of atmospheric and water column Inherent Optical Properties [IOPs].

OBJECTIVES

1) Collection of HRS data on the West Florida Shelf [WFS] and New Jersey Bight [NJB]. Process data and make it available to HyCODE team members.

2) Calibration of Ocean PHILLS-2 data.

3) Begin atmospheric data correction of HRS data.

4) Research the feasibility of placing a hyperspectral imager on a High Altitude/Long Endurance [HALE] Unmanned Aerial Vehicle [UAV].

APPROACH

Traditional optical RS algorithms for ocean color products have used empirical formulations between water-leaving radiance, $L_w(\lambda)$, and proxies for phytoplankton, e.g. chlorophyll (Gordon et al., 1983), or Apparent Optical Properties [AOPs], e.g. diffuse attenuation coefficients (Austin and Petzold, 1981), for depth-integrated data products. These algorithms use a limited number of radiance bands, and are generally limited to water conditions where the data was collected to derive the empirical relationships. HRS data provides continuous information across the visible spectrum, and as such, provides a far larger number of degrees of freedom by which to derive data products. This larger number of degrees of freedom allows for numerical techniques, such as spectral matching and linear optimization schemes (Gould and Arnone, 1998), which may provide depth-dependent water column IOP information. Unfortunately these types of numerical schemes require a “first-guess”, or some other means to

Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE **30 SEP 2001**	2. REPORT TYPE	3. DATES COVERED **00-00-2001 to 00-00-2001**

4. TITLE AND SUBTITLE **Coupling Simulated Ocean Reflectance to the Atmospheric Correction of Hyperpsectral Images**	5a. CONTRACT NUMBER 5b. GRANT NUMBER 5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)	5d. PROJECT NUMBER 5e. TASK NUMBER 5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **Florida Environmental Research Institute,,4807 Bayshore Blvd.,Suite 101,,Tampa,,FL, 33611**	8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)	10. SPONSOR/MONITOR'S ACRONYM(S) 11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution unlimited

13. SUPPLEMENTARY NOTES

14. ABSTRACT
Aircraft and satellite Remote Sensing [RS] platforms provide spatial and temporal coverage of oceanic water conditions that are unobtainable by any other cost effective means. The hope of Hyperspectral RS [HRS] data is that it will provide the necessary data stream to simultaneously describe the atmospheric and water column optical properties. The goal of these hyperspectral programs is to develop the instruments, platforms, and data analysis techniques to achieve the depth-dependent description of atmospheric and water column Inherent Optical Properties [IOPs].

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a REPORT **unclassified**	b ABSTRACT **unclassified**	c THIS PAGE **unclassified**	**Same as Report (SAR)**	**8**	

constrain their solution, requiring either in situ measurements or another methodology of providing this information. We hypothesize that simulated IOPs from nowcast/forecast systems could provide this constraining data stream, and allow for the development of true hyperspectral ocean color algorithms that use the entire collected spectra.

In addition, atmospheric correction of the HRS data has difficulty delineating blue absorbing aerosols from the water-leaving radiance signal, as most correction schemes only use the visible red or near-infrared data to remove atmospheric effects from the data. The obvious solution is to use blue wavelengths in the correction algorithms; unfortunately these are impacted by the water signal. Schemes to use the blue signal are being developed (H. Gordon, RSMAS) but rely upon simple phytoplankton chlorophyll models to address the water-leaving radiance signal. Prediction of the water-leaving signal from a nowcast/forecast system would appear to offer advantages over simplified chlorophyll models in coastal regions where the optical signal may not co-vary with chlorophyll.

The pursuit of these goals requires that we collect the RS data at sites where we are building nowcast/forecast systems. There are two sites as part of ONR's Hyperspectral Coastal Ocean Dynamics Experiment [HyCODE], off the coast of New Jersey at the Rutgers University Long-Term Ecological Observatory at 15 meters [LEO-15] and the West Florida Shelf. Readers are directed to the HyCODE web site (http://www.opl.ucsb.edu/hycode.html) for further information on this program. The instrument development, calibration, and data analysis are being accomplished in collaboration with C. Davis at the Naval Research Laboratory (Award N0001400-WX-2-0690).

WORK COMPLETED

We have flow three missions over the last year with both the Ocean PHILLS-1 (November 2000, WFS) and the Ocean PHILLS-2 (April 2001, WFS, and July 2001, NJB). Ocean PHILLS-1 refers to the PHILLS system with a 1024 x 1024 PixelVision CCD camera and an Agilent (formerly American Holographics) VS15-model 2 spectrometer. The Ocean PHILLS-2 system refers to the system with a PixelVision 494 x 652 CCD camera and an Agilent (formerly American Holographics) VS15-model 1 spectrometer. Both of these systems have a Boeing C-MIGITS IMU system for post-processing geo-rectification attached to the data collection system. These missions were flown on the NOAA Aircraft Operation Center's [AOC] Cessna Citation at 30,000 feet providing synoptic hyperspectral remote sensing data over approximately 5000 square kilometers over multiple days during each mission. These high altitude missions provide HS data at oceanographic spatial scales that can be used to create composite images that will resemble those collected by a future (hopefully) HS satellite (Figure 1 and 2).

We found that the Ocean PHILLS-1 data from July 2000 and November 2000 was extremely difficult to use due to the inability to effectively calibrate the data. Thus, we spent a tremendous amount of time in the NRL calibration laboratory during the past year trying to characterize the PHILLS-2. This exercise became our dominant work during the period, in addition to the actual data collection. We also found the geo-rectification routines originally developed for the PHILLS data stream were not working properly. Thus, trying to geo-rectify the data has also become a major time sink.

In order to help facilitate with the calibration, we elicited the help of K. Carder at USF to both help with the direct calibration of the PHILLS, as well as to collect atmospheric data during the field experiments. We covered the cost of travel for his technical support staff (Robert Steward), but the personnel time has been covered by USF. Dr. Carder's efforts have been invaluable to our efforts and the atmospheric data he collected during the 2001 HyCODE experiment in the NJB will be critical to our atmospheric correction of the HS data.

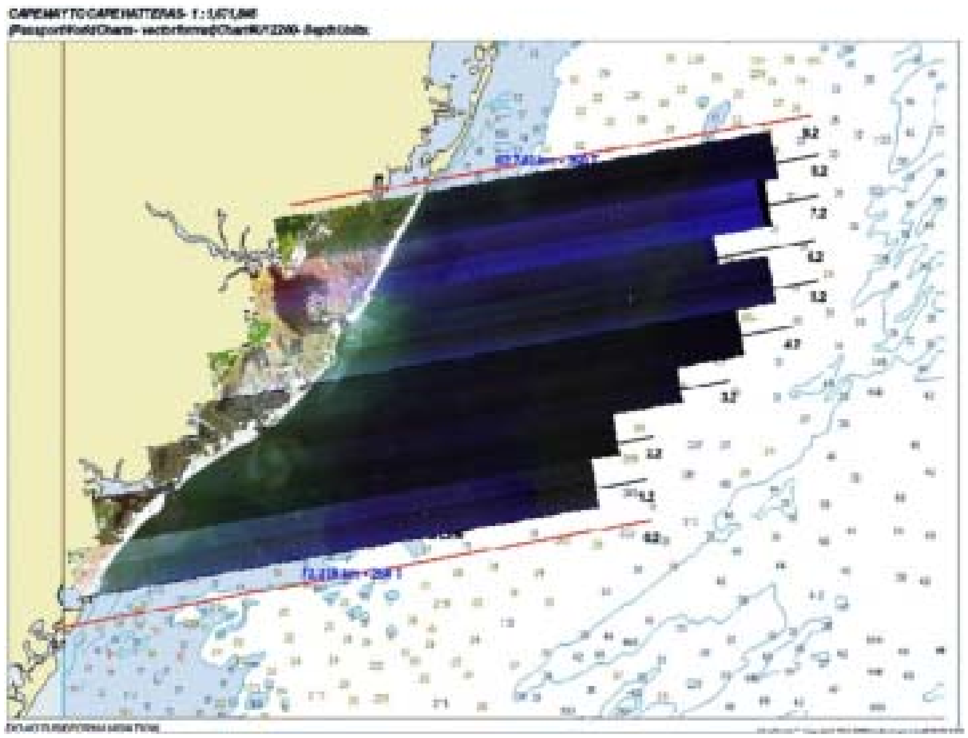

Figure 1. RGB Mosaic of July 21, 2001 Ocean PHILLS-2 Data from the 2001 HyCODE field experiment.

The NOAA Citation provided us a high altitude data stream at a fraction of the cost of HALE UAV's, nearly an order of magnitude less (~50K v. ~500K) for each of our experiments. It was decided that we should focus on the development of a radiometrically-calibrated sensor prior to attempting UAV flights, and use the Citation as the development vehicle. At such point that the sensor is robust in geo-location and radiometric calibration we will re-focus on the UAV flight vehicles.

RESULTS

Examples of our flight data are shown in Figures 1 and 2. The full data suite can be found on our web site. This data is available for the ONR HS community on a request basis. We are currently working on making the data available in an FTP format, however, each experiment is on order of ~125 GB of data, thus we are developing a system that will allow the user to select smaller spatial and spectral subsets of the entire data suite. This system should be online within the next two months.

The calibration of the PHILLS data has been frustrating in that the robustness of the instrument design did not meet our expectations. In particular, the design (originally completed by a group of engineers that have since left NRL) did not baffle or mask the zero order light (that light which is directly reflected on the holographic grating) in the spectrometer. This light is much greater than the individual wavelength bands and is projected near the blue wavelengths on the CCD array. Its effects can be seen in Figure 3 where a long-pass cutoff filter has been placed in front of the PHILLS in the calibration laboratory. In an attempt to rectify this problem NRL designed a mask to block the zero order light from entering the camera. This stopped a large fraction of the zero order light (Figure 4), but it also appears that there is still a lot for which we are not accounting. This zero order effect does appear to be proportionally related to intensity, so it may be that we can correct this in a post processing of the data.

In addition, we discovered calibration difficulties that we did not anticipate to be issues. In particular, it appears that the NIST calibration sphere that we are using is extremely red rich in output spectrum (Figure 5). This provides very little signal in the blue, ?are? we were force to use a blue filter over the calibration sphere in order to flatten the spectra of the sphere light for calibration. The difficulty is that the PHILLS calibration appears to be linear at high irradiance levels, but non-linear at low irradiance levels (We are not sure of the cause of this effect, and it is a source of calibration woes). At high altitudes over water, we are subjected to high irradiance in the blue, low irradiance in the red, causing problems in that our RS data is not within the range of our calibration series. Extrapolation of the calibration series outside of the radiance range can be problematic. Over the next few months we will begin the post process of the PHILLS-2 data stream in order to provide our best radiometrically-calibrated data to the HyCODE community.

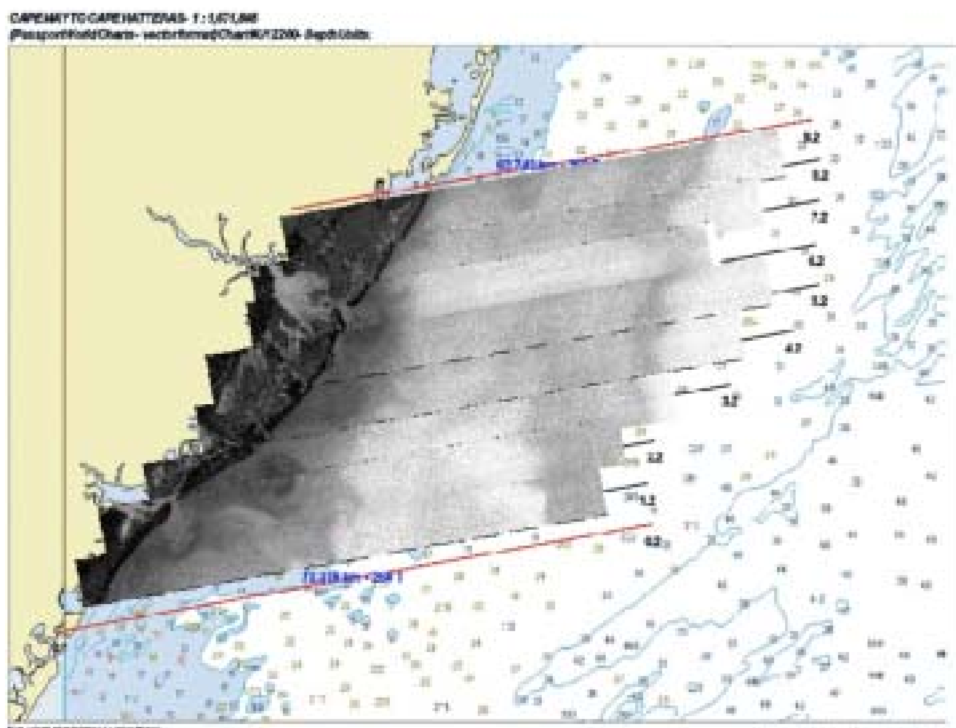

Figure 2. Ocean PHILLS-2 Ratio Product. Ratio of total upwelling irradiance of 490 to 550 nm (L_t490/L_t550); used as an indicator of total pigmented particulate material in the water column.

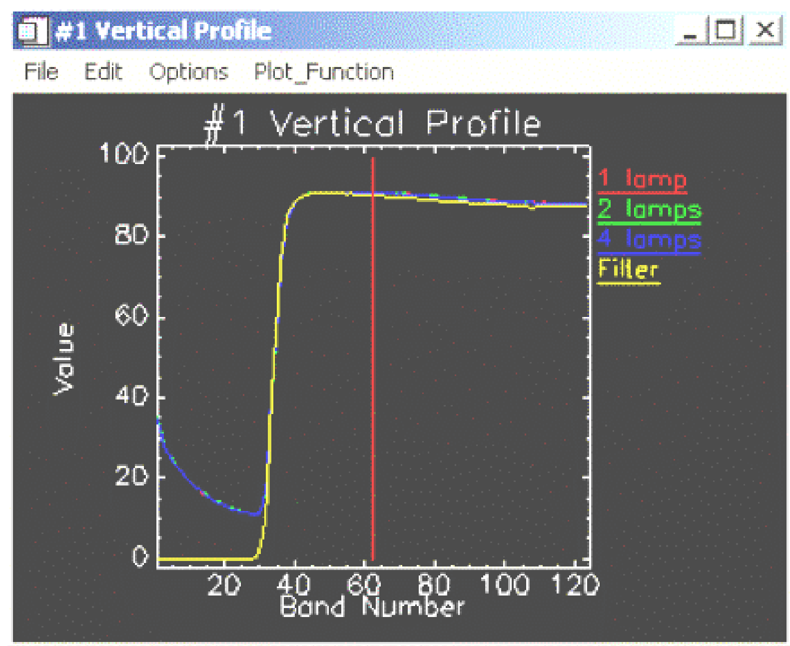

Figure 3. The camera response for the 550 long pass filter. The zero order effect can be seen in the blue to green part of the spectrum where the observed filter response differs from the real filter response. Also seen, the observed filter responses match each other – regardless of the lamp setting. This suggests that zero order effect is linear with respect to intensity

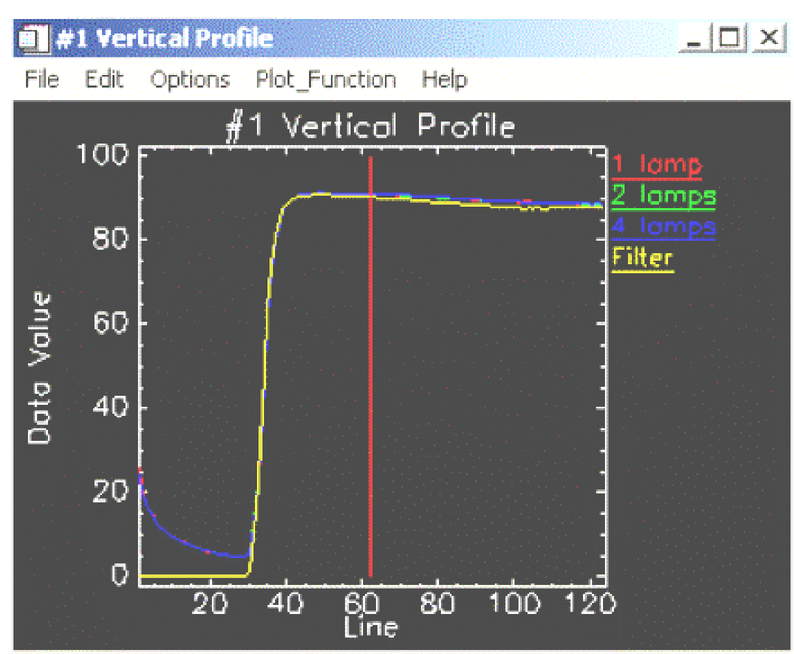

Figure 4. The camera response for the 550 long pass filter after the application of zero order mask to the CCD camera. The zero order effect is reduced, but has not been eliminated.

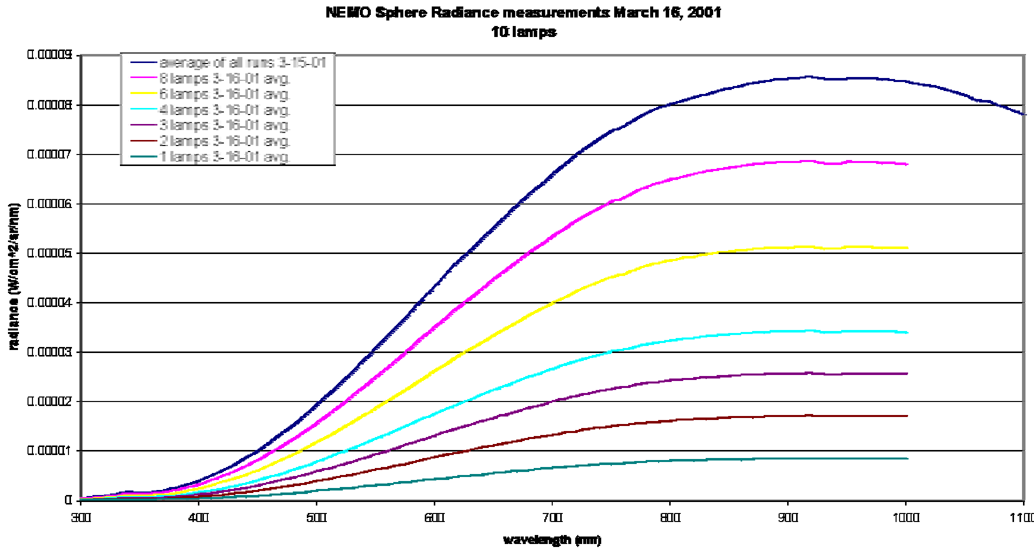

Figure 5. Spectral Radiance of NIST Calibration Sphere. Note the maximum is near 900 nm.

IMPACT/APPLICATIONS

The field of ocean color science is moving beyond empirical methods of relating water-leaving radiance (from a few wavelengths) to integrated water column pigment concentrations. The focus of new ocean color algorithms will be to invert the RS data to depth-dependent IOPs that will include all optical constituents. These algorithms will be used in visibility and performance prediction models, as well as estimating bathymetry from aircraft or space. In addition to providing depth-dependent estimates of IOPs, these new algorithms using HRS data should yield simultaneous solutions for atmospheric optical properties. This program is devoted to collecting the HRS data and developing these new algorithms.

RELATED PROJECTS

This project is closely coordinated with the ONR HyCODE (http://www.opl.ucsb.edu/hycode.html) and NRL Spectral Signatures of Optical Processes in the Littoral Zone [Spectral Signatures] programs, as well as the C. Davis's ONR-funded research (N00014-01-WX-20684).

REFERENCES

Austin, R.W. and Petzold, T.J., 1981. The Determination of the Diffuse Attenuation Coefficient of Sea Water Using the Coastal Zone Color Scanner. Oceanography from Space. Plenum Press, New York, NY, U. S. A., 239-256 pp.

Gordon, H.R. et al., 1983. Phytoplankton pigment concentrations in the Middle Atlantic Bight: comparison of ship determinations and CZCS estimates. Applied Optics, 22(1): 20-36.

Gould, R.W. and Arnone, R.A., 1998. Three-dimensional modelling of inherent optical properties in a coastal environment: coupling ocean colour imagery and *in situ* measurements. International Journal of Remote Sensing, 19(11): 2141-2159.

PUBLICATIONS

Schofield, O., Arnone, R., Bissett, W. P., Crowley, M., Moline, M. A., Glenn, S. (2001) Cyclops is dead: Tapping the international constellation of ocean color satellites. Backscatter (submitted)

Schofield, O., Bergmann, T., Kohut, J., Glenn, S. M., Pegau, W. S., Boss, E., Davis, C., Synder, W., Bowles, J., Kappus, M., Arnone, B., Weidemann, A. Bissett, W. P., Moline, M. A., Heine, E. L., Case, J., Herren, C. (2001) Adaptive sampling of a "Red River" in the coastal waters using a coastal ocean observatory. EOS (submitted)

Bissett, W. P, Schofield, O., Glenn, S., Cullen, J. J., Miller, W. L., Plueddemann, A. J., Mobley, C. D., (2001) Resolving the impacts and feedbacks of ocean optics on upper ocean ecology. Oceanography, 14:(in press).

Schofield, O., Bergmann, T., Bissett, W.P., Grassle, F., Haidvogel, D., Kohut, J, Moline, M., Glenn, S. (2001). The Long Term Ecosystem Observatory: An integrated coastal observatory. Journal of Oceanic Engineering, (in press).

Walsh, J.J., B. Penta, D.A. Dieterle, and W. P. Bissett. (2001) Predictive ecological modeling of harmful algal blooms. Human Ecological Risk Assessment, (in press).

Walsh, J.J., Haddad, K.D., Dieterle, D.A., Weisberg, R.H., Li, Z., Yang, H., Muller-Karger, F.E., Heil, C.A., and Bissett, W.P., (2001). A numerical analysis of landfall of the 1979 red tide of *Karenia brevis* along the west coast of Florida. Continental Shelf Research, (in press).

Bissett, W.P., Schofield, O., Mobley, C., Crowley, M.F., and Moline, M.A. (2000). In "Methods in Microbiology, Volume 30: Marine Microbiology" (J.H. Paul, ed), Optical Remote Sensing Techniques in Biological Oceanography. Academic Press, London. 519-540.

Schofield, O., Grzymski, J., Bissett, W.P., Kirkpatrick, G., Millie, D.F., Moline, M., and Roesler, C.S. (1999). Optical monitoring and forecasting systems for harmful algal blooms: possibility or pipe dream? Journal of Phycology, 35, 1477-1496.

Walsh, J.J., Dieterle, D.A., Muller-Karger, F.E., Bohrer, R., Bissett, W.P., Varela, R.J., Aparicio, R., Diaz, R., Thunell, R., Taylor, G.T., Scranton, M.I., Fanning, K.A., and Peltzer, E.T. (1999). Simulation of carbon-nitrogen cycling during spring upwelling in the Cariaco Basin. Journal of Geophysical Research 104, 7807-7825.

Bissett, W. P., J. J. Walsh, D. A. Dieterle and K. L. Carder (1999) Carbon cycling in the upper waters of the Sargasso Sea: I. Numerical simulation of differential carbon and nitrogen fluxes. Deep-Sea Research, 46(2):205-269.

Bissett, W. P., K. L. Carder, J. J. Walsh and D. A. Dieterle (1999) Carbon cycling in the upper waters of the Sargasso Sea: II. Numerical simulation of apparent and inherent optical properties. Deep-Sea Research, 46(2):271-317.

Bissett, W. P., J. S. Patch, K. L. Carder and Z. Lee (1997) Pigment packaging and chlorophyll a-specific absorption in high-light oceanic waters. Limnology and Oceanography, 42(5): 961-968.